ONE VIEW OF THE ROLE OF SCIENTIFIC INFORMATION IN THE SOLUTION OF ENVIRO-ECONOMIC PROBLEMS

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ABSTRACT

The northeast coast of the United States is contaminated by a variety of industrial-related organic and heavy metal contaminants. In this presentation we discuss a coastal area in Southeastern Massachusetts which was contaminated over a period of four decades by polychlorinated biphenyl (PCB) waste discharges from two electronics component manufacturers. Although there is no longer substantial active discharge from these two plants, severe and long-lasting contamination persists and places major constraints and costs on several commercial activities, including fishing and harbor development. Contamination has also raised public concern regarding possible human health hazards.

We report PCB concentration levels in sediment and several marine animal species and review how the extent and seriousness of this pollution was discovered by an academic laboratory (Woods Hole Oceanographic Institution), a non-profit conservation organization (Massachusetts Audubon Society), and a federal regulatory agency (U.S. Environmental Protection Agency). Research conducted under the Mussel Watch Program, using the common blue mussel *Mytilus edulis* as a sentinel organism, demonstrated that the Acushnet River estuary-New Bedford Harbor area of Buzzards Bay was highly contaminated with PCBs. We discuss this observation relative to PCB contamination in other areas of the U.S. coast. We found total PCB concentrations as high as 49 μg/g dry weight (gdw) in *Mytilus edulis* sampled at the harbor entrance, compared to concentrations of 0.15 μg/gdw at less polluted stations on the nearby coast. Lobster, *Homarus americanus*, shows the same disparity with harbor samples yielding as

much as 86 μg/gww (wet weight) compared to nearby controls containing 2-13 μg/gww. In comparison, PCB levels in mussels from other urbanized areas of the northeast U.S. coast (i.e., Boston, New York) contain 0.6-0.8 μg/gdw, clearly documenting the severity of New Bedford Harbor contamination. This contamination has now been confirmed by several state and federal agency laboratories or their contract laboratories.

We present an overview of the complexities encountered in the analysis of organics in environmental samples and discuss the necessity of interlaboratory comparison when several laboratories are involved in the production of similar data. In addition to analytical complexities, we also address the roles that research laboratories and monitoring laboratories can play in the solution of an environmental problem. Analytical methods for determining organic pollutants in environmental samples are constantly evolving from state-of-the-art research toward the more routine monitoring stage. Because of this, a government agency charged with resource management must be able to integrate the newest research results with more conventional monitoring information into a rational and coherent policy. We use a case of PCB contamination to show how a limited number of high resolution analyses can be used together with more routine, less expensive measurements to greatly improve the understanding of a specific pollution problem.

Academic research laboratories can make relevant contributions to the solution of environmental problems by providing assistance in the interpretation of monitoring data within the context of the dynamics of natural systems. Close liaison between research, monitoring and regulatory activities should provide early warnings of impending problems and allow for greater flexibility of response.

INTRODUCTION

The past decade has seen substantial progress in defining environmental quality problems and some progress in mitigating several of them (SCOPE, 1982; I.O.C., 1982; U.N., 1976; Goldberg, 1976, among others). Lessons learned from studies of one type of environmental contaminant or from studies in one particular location can often lead to a general strategy for defining and solving problems with other contaminants in other locations. The solution to many of these problems has been and will continue to be expedited by the application of state-of-the-art scientific research to the definition of the problem.

Polychlorinated biphenyls (PCBs) are an example of environmental contamination that has been identified during the last 15 years. PCBs are among several man-made organic chemicals which have proven to be recalcitrant and widely dispersed in the marine environment (NAS, 1979; U.N., 1976; Kimbrough, 1980). Despite the recognition that these environmental pollutants can cause adverse impacts to natural ecosystems and under certain conditions pose a health threat to man, PCBs are still manufactured and released in some countries (NAS, 1979; Kimbrough, 1980). In addition, substantial quantities of PCBs remain in use in some countries as a result of past production or importation and much of the PCBs already released to the environment are still present in various segments of contemporary ecosystems. For example, in the United States, where the total cumulative production of PCBs through 1975 was 6.1×10^8 kg (670,000 tons), the amount released to the environment is estimated at 8.2×10^7 kg (90,000 tons), of which 6.8×10^7 kg (75,000 tons) are still present. An additional 13×10^7 kg (143,000 tons) are present in landfills or equipment dumps and could eventually enter the environment (NAS, 1979). Thus, despite the cessation of manufacturing of PCBs in the United States, problems associated with PCB pollution of ecosystems have not been eliminated. We contend that efforts to minimize the adverse impact of the PCBs already released, and to clean up areas of severe PCB contamination, require further research on the chemistry, biogeochemistry and biological effects of these compounds. This research will provide insight into environmental processes which control the fate and effects of PCBs and other man-made organic chemicals which have been or may be released to the environment.

Much of the world's population and the associated production and use of industrial chemicals is found in coastal areas and this has resulted in the deterioration of environmental quality in coastal waters. The present rapid rate of industrialization of coastal areas in some countries emphasizes the need for wise management practices to minimize the types of adverse effects that have been experienced by the more industrialized countries. It is logical to learn from past mistakes and successes in dealing with coastal environmental quality, however scientific research by itself cannot solve these problems. The results of research need to be introduced and explained to local, regional, national and sometimes international agencies in a manner that allows up-to-date scientific knowledge to enter the decision-making process, along with socio-political and economic factors. This logical and by no means new thought is easier to state than to put into practice. The need for scientific data has been recognized and, in some cases, mandated by law or regulation. If this data is to be translated into usable information, open lines of communication between the scientist and the user must exist.

We have been studying the biogeochemistry of organic pollutants in the marine environment for several years. During the past five years, we have conducted research on and assisted in the monitoring connected with a severe PCB pollution problem in a harbor-estuarine area of Buzzards Bay, Massachusetts, USA. In this paper, we briefly review this problem, present and interpret some of our data, and discuss the role that scientific research can play in defining and helping to eventually solve this problem. We hope that our experiences and our thoughts about the interactions between academic research scientists and various government agencies will be of use to others dealing with similar problems even if the political organization and regulatory arrangement are different.

Buzzards Bay and the Acushnet River Estuary

Buzzards Bay, Massachusetts is located on the northeastern United States coast (Figure 1) and covers about 775 km^2. Freshwater discharge into Buzzards Bay is estimated at 27 m^3 sec^{-1}, resulting in salinities of about 31-33°/.. (Bumpus et al., 1974). The Acushnet River is a small river which enters the bay on the western shore and forms the Acushnet River estuary, a fine natural harbor of commercial importance since the last century. In the Acushnet River estuary, salinity can be as low as 20°/... Surface waters of the harbor contain about 1-4 mg/L of suspended matter, an amount similar to that found in the rest of Buzzards Bay except for bottom waters where resuspension by tidal currents can create a 2-3 m thick boundary layer containing 10-35 mg/L suspended matter. Summerhayes et al. (1977) reviewed the existing knowledge of sediments and circulation in Buzzards Bay and the Acushnet River Estuary. New Bedford, located on the west bank of this harbor, is an old city that has a long history of ocean-related and industrial activities. This port city has a population of about 98,500 and is the fourth largest city in Massachusetts, U.S.A. It was the world's largest whaling port in the early 19th century and in 1845 it was the fourth largest port in the United States, surpassed only by New York, Boston, and New Orleans. New Bedford's ties with the sea remain strong as it is the largest revenue-producing fishing port on the U.S. east coast (Weaver, 1982; NOAA, 1982), with the bulk of the fish being caught on or near the offshore George's Bank area.

The textile industry replaced the whaling industry as the largest commercial venture in the area in the late nineteenth century. Economic prosperity in that industry lasted until the Great Depression of the 1930's, but in subsequent years textiles moved out of the city. Since World War II, the city has broadened its economic base by attracting new industries to utilize some of the vacated textile mills. Aerovox, Inc. and Cornell Dubilier, Inc. are two electronic components manufacturing companies which were attracted to the area and are located in vacated textile mills. Both companies used PCBs in the manufacture of electronic capacitors, and during the manufacturing process PCBs have leaked into the Acushnet River estuary and Buzzards Bay via waste disposal and effluent discharge. We will not debate the issue of legal responsibility in this paper, but we will state that during most of the time that PCBs were used by these companies, the environmental problems associated with PCBs were not widely known. Thus, the only incentive to prevent leakage was the economic loss. In the early 1970s, environmental quality problems associated with PCBs became more widely documented and regulatory actions were promulgated (NAS, 1979). The PCB problem in the Acushnet River estuary was not discovered until 1974 (M. Blumer, pers. comm.), and the data which indicated that a severe problem might be present were not collected until 1975-1976.

Buzzards Bay lies in the heavily populated northeastern U.S. and is used intensively for commerce, commercial and recreational fishing, tourism and recreation. Major impacts to the harbor system due to structural alterations (e.g. closure of the harbor by a hurricane barrier) and to waste discharges have already been documented and are reflected in such actions as the closing of local areas to shellfishing. Contamination also affects the economy of the city, as harbor development projects continue to be delayed because disposal of contaminated dredge spoil that is classified by the U.S. EPA as hazardous waste has not yet been resolved.

METHODOLOGY

Sampling

Fish and crustacea were collected using a small otter trawl. Bivalves were collected either with dredges or by hand, lobsters were collected both by baited traps and by trawl net. Surface sediments were collected using a hand-held grab sampler in some areas and box cores (Soutar-type box core, Oceanic Instruments, San Diego, California) in others. The box corer collects a nearly undisturbed core which permits careful examination of lithology and depth distributions of contaminants. Water samples were taken with a glass Bodman bottle designed to minimize organic contamination during sampling (Gagosian et al., 1979). Water samples were filtered through 0.4 μm glass fiber filters which had been solvent extracted. Sampling procedures were designed to avoid contamination during the sampling process (Harvey and Giam, 1976).

All sediment, organism and suspended particulate matter samples were frozen at -20°C until analysis. Water samples were extracted within 10 to 12 hours of collection and were preserved with methylene chloride shortly after collection.

Extraction and Analysis

Whole organisms or excised tissues were homogenized and subsamples were freeze-dried to obtain dry weights. Subsamples of 5-15 g wet tissue homogenate were extracted by alkaline hydrolysis and then back-extracted into diethyl ether. The ether extract was evaporated to near dryness and then column chromatographed on silica gel. The eluate from column chromatography was concentrated for gas chromatography analyses. Sediment samples were Soxhlet-extracted without drying with toluene-methanol followed by partitioning into hexane and column chromatography similar to that described above. Water samples were extracted using methylene chloride followed by concentration of the extract and column chromatography as above. Filtered particulate matter was extracted in a small Soxhlet apparatus using procedures scaled down from that of the sediment extraction.

Fractions from column chromatography were analyzed by gas chromatography on packed columns and in several cases by glass capillary gas chromatography. Quantitation of PCBs was by peak area comparison of five to eight peaks in sample chromatograms with the same peaks found in chromatograms of Aroclor 1254 and Aroclor 1242 standard mixtures.

Several samples were analyzed by glass capillary gas chromatography-mass spectrometry to confirm PCB identifications. Details of these analyses and of the analyses previously described are given in Farrington et al. (1982).

CHRONOLOGY OF THE PCB PROBLEM IN THE ACUSHNET RIVER ESTUARY

Table 1, modified from Weaver (1982), presents a chronological synopsis of the important events that occurred in the development of the PCB problem in the estuary. Many of the data that allowed the initial assessment of this problem were produced by a variety of academic researchers who discovered the situation almost accidentally and as an aside to other projects. Preliminary indications of PCB contamination in the general area came in 1974. A survey report of concentrations of a variety of chemicals in surface sediments of Buzzards Bay at several locations indicated the presence of PCBs at the 100 to 500×10^{-9} g/g dry weight (i.e. 0.1-0.5 ppm) concentration (Gilbert et al., 1974). The data were evidently not viewed with much alarm at that time, as the concentrations were not much different from those which would be expected near an industrialized coast and few other data were available for comparison.

A second report in 1974 came from a study of petroleum hydrocarbon contamination of surface sediments in Buzzards Bay. One of the stations, located in the outer harbor near Clark's Point (Figure 2), was sampled in 1973 by the late Dr. Max Blumer and co-worker Dr. Walter Giger of the Woods Hole Oceanographic Institution (Giger and Blumer, 1974). They reported that concentrations of PCBs were so high as to cause interference with the mass spectrometric measurements of polycyclic aromatic hydrocarbons. Dr. George Harvey and co-workers at W.H.O I. had been studying PCB distributions in the North Atlantic Ocean and subsamples given to them were found to contain PCBs at concentrations of 8×10^{-6} g/g dry weight (i.e. 8 ppm) (Harvey et al., 1974; Harvey and Steinhauer, 1976). Although these high concentrations of PCBs were from a single sample, they suggested that a severe pollution problem in the estuary might exist.

Harvey &
Steinhauer

The National Science Foundation (NSF), sponsoring research of pollutant transfer processes, funded an intercalibration cruise in the western North Atlantic in the summer of 1976 to provide an assessment of the contentious issue of measurements of low concentrations of PCBs in open ocean waters. This cruise brought Dr. Robert Risebrough of Bodega Marine Laboratory, Bodega Bay, California and his co-workers to Woods Hole for a short time. In addition to their involvement with the IDOE-NSF program, they had also been collaborating with Dr. Ian Nisbet of the Massachusetts Audubon Society in a study of chlorinated pesticides and PCBs in birds and bird eggs of the northeastern U.S. coast. Elevated PCB concentrations in some samples from Buzzards Bay were observed as a result of this collaboration. Risebrough and others were also involved with our own laboratory in the U.S. Environmental Protection Agency-funded Mussel Watch program, which was sampling and analyzing mussels (*Mytilus edulis*) and oysters (*Crassostrea virginica*) collected from the entire U.S. coastline (Goldberg et al., 1978). During this visit, the group from Bodega sampled water and mussels at one station in the Acushnet River estuary and at two locations in Buzzards Bay. They reported in a personal communication to us in 1977 that the mussels in the estuary contained 110×10^{-6} g PCB/g dry weight (i.e. 110 ppm).

We compared the data from Risebrough et al. with our own data on PCB concentrations in mussels from the 1976 Mussel Watch collections of the Massachusetts coast (Figure 3 and Table 2). This comparison convinced us that concerns raised as a result of the earlier reports were well founded and that further investigations were warranted. We contacted the Massachusetts Department of Environmental Quality Engineering (Mass. DEQE) to express our thoughts about the potential seriousness of the PCB contamination in the Acushnet River estuary area and Buzzards Bay. We found that the U.S. EPA had recently (1976) reported some measurements of PCBs in sewage effluents, sediments and organisms in the New England area which indicated elevated concentrations of PCBs in the Acushnet River estuary area. We agreed with Mass. DEQE that a review of all existing data would be appropriate to more clearly define the exact nature of the situation.

We met with Mass. DEQE and other state agency officials (i.e. Division of Marine Fisheries (DMF)) over the next several months, and reviewed survey data from various locations in the harbor. Concentrations of PCBs in some of the organism samples were quite high, in excess of the recommended 5×10^{-6} g/g wet weight (i.e. 5 ppm) action level set by the U.S. Food and Drug Administration (U.S. FDA). From this initial contact with Mass. DEQE, we learned that:

1) Mass. DEQE scientists and staff were enmeshed in myriad environmental quality problems, and increased demand for action by the public (including academic researchers) and by elected officials greatly strained their resources.
2) The personnel and analytical instrumentation available to the state agencies at that time did not appear sufficient to respond rapidly and efficiently to a problem of the magnitude found in the Acushnet River estuary and simultaneously perform routine tasks.
3) A reluctance existed within the state agencies to enter into a collaboration with an independent academic institution. This reluctance may have been based on a desire

to avoid unnecessary public alarm and adverse publicity and on a need to avoid any activity which might prejudice their legal and regulatory responsibilities. Close interaction with an outside organization over which they had no control in terms of public statement restrictions or research plans probably did not appear prudent.

It was not until our laboratory was involved in the scientific response to the Argo Merchant oil spill which occurred during the winter of 1975-1976 that one of us (JWF) met with the Governor of Massachusetts and his Secretary for Environmental Affairs and had the opportunity to discuss the oil spill and general problems of coastal environmental quality. We were asked to provide advice on the Acushnet River estuary PCB problem and made several verbal recommendations to the state agencies at that time.

Our first recommendation addressed the problem of intercalibration between the several laboratories that were producing PCB data. We assembled several data sets scattered among offices within state agencies into a single set of data to assess present knowledge of the problem. The regional office of the U.S. EPA and the Mass. DEQE have since expanded this effort and a computerized data management system for New Bedford area PCB data is currently being established by an U.S. EPA contractor. We also convened a meeting of all of the laboratories that were analyzing for PCBs to discuss sampling and analytical methodology. This meeting, held in Woods Hole in February 1980, provided an opportunity to present some of our data to the agencies and to review some recent research conclusions of which they were not aware.

Inter-
calibratio

Our second recommendation to the state agencies was to treat the harbor-estuarine area as a dynamic system and to introduce the concept that harbor sediments may not be a permanent sink for organic contaminants. We used a recent study of trace metal distributions in the harbor and Buzzards Bay sediments as an example. Summerhayes et al. (1977) had suggested that sediments and associated trace metals accumulated inside the harbor as a result of circulation patterns, discharge points in the harbor and the restriction of flow imposed by the hurricane barrier. They also suggested that the harbor could be viewed as a "leaky sink" with respect to the trace metal contaminants and that some trace metals had been or were being transported into the western part of Buzzards Bay. Our reasoning, based on an assessment of the literature (NAS, 1979; EPA, 1976; Harvey et al., 1976) was that PCBs were also associated with particulate matter and therefore might be transported in a manner similar to the trace metals.

Our third recommendation was that the migratory habits of the commercially valuable marine organisms then being analyzed should be considered and that an expansion of the commercial fish survey beyond the immediate harbor area to the larger area of the bay should be instituted. Concentration of PCBs found in individuals of a transient population cannot easily be related to contamination in any one place, and further research on the biology of the population as well as on the transport and degradation processes affecting the contaminant are needed.

By late 1976, the news media entered the arena and reports began to appear in the local press and on television. Local elected officials tended to downplay the PCB contamination problem, as they were trying to attract new industry to the area and were legitimately concerned that reports of PCB contamination would alarm the public and would be detrimental to the established fish-

Particulate
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ing industry and to their efforts to expand the city's industrial base. Increased public exposure appears to have slowed, rather than enhanced, the response of some government agencies. This withdrawal is understandable because the news media tended to polarize the issues, seeking areas of conflict. Under such intense scrutiny, any action taken by agency officials could be criticized. Nevertheless, to their credit, the state agencies maintained a survey monitoring program as well as official interest in the problem, even though individuals within an agency seemed to be trying to maintain low public visibility.

After reviewing the available data on PCB concentrations in lobsters and finfish sampled in the Acushnet River estuary and western part of Buzzards Bay, the Massachusetts Department of Public Health (Mass. DPH) issued a warning in 1977 that lobsters and bottom-feeding finfish from the Acushnet River Estuary and outer New Bedford Harbor area (Areas I, II, III of Fig. 2) should not be consumed. Many samples contained PCB concentrations in excess of the 5 ppm wet weight maximum limit recommended for seafood by the U.S. FDA. The U.S. FDA ruled that it did not have jurisdiction since the fish and lobsters were caught and sold locally and did not enter interstate commerce. The Mass. DPH closure action was apparently viewed with reservations by other state agencies and local officials. In our experience, overlapping and even conflicting responsibilities are often found between agencies dealing with environmental problems. If no single agency has been authorized to take a lead role, confusion and conflict can result. There was considerable confusion at this point and for at least a subsequent year as each state agency (see Fig. 5) attempted to define its jurisdiction and responsibility over aspects of the problem. The Mass. DPH acted because it had responsibility to protect public health. However, the location of authority to enforce any Mass. DPH ban on fishing was in question, and they were constrained in any case because they lacked the personnel and small boats to patrol the area.

By the end of 1977, academic research scientists were convinced there was a potentially serious PCB contamination problem in the area. State agency officials and local elected officials, with the exception of the public health department, generally were more conservative in their reaction. We feel this occurred for three reasons. First, the research scientists involved had been studying the general aspects of the fate and effects of environmental pollutants and had a wider knowledge of the national and worldwide data base. They knew that the concentrations of PCBs in the samples thus far analyzed from the harbor area were quite high compared to other samples from coastal and aquatic areas of the world. They also knew of the potential for wider contamination in the area of Buzzards Bay. In addition, the researchers could openly discuss the potential severity of the problem because they would not be seriously affected by any of the political side effects that concerned state and local officials. State agency officials, lacking access to much of the recently accumulated data, were generally not able to place the situation in the same regional or national perspective. They were also concerned about adverse publicity and remained to be convinced by more solid evidence that the problem was sufficiently serious to risk a threat to the fishing industry. Also, a conservative official reaction was prompted because there had been a change in state administration and newly appointed state officers not only required time to learn about the situation but also wished to institute independent policies. Finally, no irrefutable dramatic evidence such as human illness could be attributed to PCB contamination. For all of these reasons, the response of state agencies was slowed.

During 1977 and 1978, we transmitted our unpublished Mussel Watch data and other unpublished data of Risebrough and Nisbet (pers. comm.) on PCBs in mussels, fish and lobsters to local and state officials. We compared concentration levels of PCBs in fish and lobsters from the area with some data in the literature. We now understand that the comparative data of the Mussel Watch program given in Tables 2 and 3 played a role in convincing several of the local officials that the PCB problem was severe. Clearly, the high concentrations of PCBs in New Bedford mussels sampled at Fort Phoenix were much higher than those found elsewhere on the east coast. Details of the data in Table 2 and Figure 4 are contained in Farrington et al. (1982). A key person who was convinced the problem required more attention was State Representative Roger Goyette, elected to the Massachusetts legislature from New Bedford. In 1979, he formed an Ad Hoc Committee that provided a more formal basis by which various state and local officials, local civic and business leaders and academic researchers could be brought together to better define the extent of the problem and to draw up plans to alleviate it. Goyette asked one of us (JWF) to coordinate the technical activities of this committee. As a result of periodic meetings of the Ad Hoc Committee over a period of two years, general awareness of the problem within the agencies increased and more rigorous and critical discussions of the various data collections ensued. The Ad Hoc Committee also made the problem more visible on the national level, and representatives from the offices of the Congressman and Senators began to participate in these deliberations and to assist in a search for funds to study amd clean up the problem (see Fig. 5).

In 1979, Mass. DPH changed the warning issued in 1977 to a closure for the harvesting of lobsters, finfish, and shellfish as indicated in Figure 2. During the period 1979 to 1980, our laboratory and those of two state agencies (DEQE and DMF) began to more actively pursue field sampling and analysis in order to better define the geographic extent and severity of the problem. Two small-scale epidemiology studies of PCBs in blood samples of volunteers in the city of New Bedford conducted by the Mass. DPH, the Harvard School of Public Health and the National Center for Disease Control in Atlanta, Georgia revealed that many of the blood PCB concentration levels were among the highest recorded in the nation. These results have reinforced the data developed through other sources and have given impetus to the effort being made to address this problem. In 1980, the Mass. DEQE and the U.S. EPA designated the PCB problem as a priority issue. The costs of dredging contaminated sediments in a safe manner to remove the PCB contamination problem were estimated by an engineering consultant and ranged as high as 130 million dollars. A sum such as this would burden the financial resources of the city and state beyond reason and it was generally agreed that federal assistance would be required to fund a clean-up project.

In 1981, in anticipation of funds from the newly-created federal fund for cleaning up hazardous waste sites (Comprehensive Environmental Response, Compensation and Liability Act of 1980 - "Superfund"), the Secretary for Environmental Affairs formed a task force, chaired by the Mass. DEQE, to define the scientific, engineering and socio-political needs involved with an effective clean-up. Through this state-level interagency task force, communication has improved and conflicts such as that seen between agencies over the ban on fishing in the harbor are being resolved. The Mass. DEQE has nominated the harbor-estuarine area as a priority site under "Superfund" legislation and the area has recently been added to the "Superfund" list, making the clean-up efforts eligible for these special federal funds. The required first steps to apply for Superfund assistance have now been taken and the need for scientific input has escalated.

SCIENTIFIC CONTRIBUTIONS TO PROBLEM DEFINITION AND SOLUTION

In addition to documenting the relative severity of the problem as discussed above, our laboratory has made several other contributions to the Acushnet River estuary contamination problem.

Aroclor Mixtures and Specific PCB Isomers

The analytical methods used by the state agencies and contracting companies in the initial analyses were designed for rapid screening. The method had primarily been applied to samples in which Aroclor 1254-type mixtures predominated as determined by gas chromatography. Since the mixture of PCBs with a closest match to the Aroclor 1254 mixture is usually found in samples from the marine environment (NAS, 1979), analysts accustomed to searching for only 1254 might not realize that other peaks seen in their chromatogram might also be PCBs. The predominance of this mixture in a variety of environmental samples is attributed to the greater loss to the atmosphere and to biological degradation or metabolism of the less chlorinated PCB isomers. These less chlorinated PCBs make up the other Aroclor mixtures that were heavily used in a variety of commercial and industrial applications: Aroclor 1016 and Aroclor 1242. In general, the longer the distance of transport or the greater the time the material spends in the environment, the less likely that 1016- or 1242-type mixtures will be found.

However, both we and Risebrough and his colleagues found in our initial packed column analyses that the PCB mixture from the Acushnet River estuary bivalves contained about equal amounts of 1242 and 1254. The Aroclor 1016 mixture is quite similar to Aroclor 1242, differing primarily in the removal of 3 isomers, and would give an almost identical analytical signal to Aroclor 1242. We analyzed several sediment samples, water samples, and several different species of marine organisms and showed that the Aroclor 1242 (1016) was present in many of the samples from the estuary in amounts equal to or greater than the Aroclor 1254 mixture (see Tables 3-6). This implies that results of initial surveys conducted by other laboratories might be low by a factor of 2 to 4. Also, the ecosystem contained a broader range of PCB mixtures than was initially identified, a fact which could potentially be of significance to public health aspects of the problem and to considerations of impacts on natural resource populations.

We also applied high resolution glass capillary gas chromatography analyses to several of each type of sample, and some representative chromatograms are given in Figure 4. In general, water, particulate matter, sediments and bivalves from the estuarine area contained a similar mixture of PCB isomers, although each sample type showed differences. These variations may be the result of differing physical chemistry or differing biochemistry for each isomer. We continue to investigate this question. Thus, high resolution glass capillary gas chromatography (Figure 4) confirms our conclusions from packed column analyses that PCBs found in environmental samples contain a mixture of Aroclors 1242 and 1254 and it also permits more precise investigation of individual isomer distribution.

Results of high resolution glass capillary gas chromatographic analyses of crustacea and fish were more complicated than the bivalve sample. Each species had a clearly different PCB isomer composition and this is most clearly seen in the crustacea (Figure 4). The lobster (Homarus americanus), a valuable commercial species, is the species most relevant to our present discussion. Packed column gas chromatography analysis in the case of lobsters shows primarily an Aroclor 1254-type distribution and we have quantitated in this way because the current U.S. FDA guidelines are based on packed column analysis. However, the high resolution gas chromatograms in Figure 4 clearly show that the mixture of PCBs in lobsters is very different than the Aroclor 1254 standard. Essentially, three or possibly four isomers predominate, with two isomers not resolved even by the high resolution glass capillary column. The pattern of isomer peaks in the chromatogram for PCBs in lobsters is somewhat similar to that reported for bird eggs and human milk in a survey of various sample types using high resolution glass capillary g.c. (Ballschmiter and Zell, 1980; Zell and Ballschmiter, 1980a, b; Ballschmiter et al., 1981). We think this distribution in lobsters results from the relatively more rapid metabolism of some isomers, leaving the observed pattern of the more recalcitrant residual isomers. This hypothesis is in agreement with the earlier work of Schulte and Acker (1974).

We have discussed these findings with state agency officials and have suggested the following:

The present U.S. FDA guidelines of 5 ppm wet weight are primarily based on physiological experiments with whole Aroclor mixtures. The altered mixture of PCB isomers found in lobster makes up a relatively small proportion of the total Aroclor mixtures. Thus, the 5 ppm of PCBs in the lobster has a markedly different composition from the commercial Aroclor mixture that was used in the physiological research, and could have a much greater or a much lesser adverse effect than the unaltered Aroclor mixture. The biological activity of the isomers predominant in the lobsters remains unknown and current experiments on individual isomers may show that acceptable PCB concentration levels to adequately protect public health could be dramatically different from those presently in use. This issue is currently at the research stage, but we have emphasized to the appropriate agencies that such information, when available, could be critical to the manner in which they clean up the estuary and to the amount of money necessary to do it. If the agencies can be forewarned of possibilities such as this, the actions they take will perhaps be more flexible and adaptable to future changes in our understanding of a given problem.

Distribution of PCBs in Organisms

Initial analyses by the Mass. DPH and Mass. DMF were done on whole lobster samples. We brought to their attention the fact that very high concentrations of PCBs are found in the tomale of the lobsters (Table 6) relative to lobster flesh. The tomale is the digestive gland of the lobster and presumably also functions as a main detoxification site for xenobiotic compounds. The tomale is considered a delicacy to many people who eat lobster and this is the reason that it is included, along with the claw and tail muscle, as the edible portion for analysis. Our separate analyses of lobster viscera, which is mainly composed of tomale on a weight basis, and lobster claw and tail muscle tissue (Table 6) revealed that, if the tomale was excluded from the edible portion, then the lobsters we analyzed would be acceptable for marketing under existing

U.S. FDA regulations. However, the Mass. DPH decided that a warning to avoid eating the tomale would not be as effective in protecting public health as the total closure of the local lobster fishery.

Depth Profile of PCBs in Sediments

The agencies needed an estimate of the distribution and amount of PCBs present in harbor sediment in order to plan an effective and economical clean-up strategy. Using some of our own surface sediment analyses (e.g., Table 5) and depth profiles in cores, and comparing PCB concentrations in this limited number of samples with the more extensive trace metal data of Summerhayes et al. (1976), we were able to provide an estimate of the total weight of PCBs in the harbor. We calculate that at least 110 tons of PCBs are in the upper 50 cm of the harbor and that dredging of the upper 50 cm of sediment would remove most of the PCB contaminated sediment. A rough calculation of costs that would be required to dredge and securely contain this amount of sediment made it apparent that federal funds would be necessary to assist the city and state. Since our initial estimates, contaminated hot spots with even higher PCB concentrations have been located and it is now estimated that the total PCB load in the harbor sediments may be as high as 300 tons.

PCB Concentrations Elsewhere in the Estuarine Ecosystem

Most initial survey measurements of PCB concentrations in organisms were in the important commercial species (e.g. lobsters and hard shell clams, *Mercenaria mercenaria*) and in sediments. We surveyed a much broader range of organisms, including infauna and species with no present commercial value. The results of these analyses clearly demonstrate that high PCB concentrations are pervasive throughout the ecosystem. A knowledge of this PCB distribution

Total mass estimate

will be important as we try to understand the routes and rates of PCB transport and degradation in the ecosystem.

Effective Monitoring Systems

We introduced the concept of the "Mussel Watch" (NAS, 1980) at the local level within Buzzards Bay and expanded our network of stations in the bay (Table 3). We also introduced the procedures for transplanting mussels developed by Phelps and co-workers (Phelps and Galloway, 1979, 1980; Widdows et al., 1981) to provide a series of sentinel organism stations along presumed gradients of PCB contamination in the water from the harbor to other parts of the bay (Farrington et al., in preparation). This monitoring system should prove to be a cost effective component of monitoring during dredging operations to see if extensive PCB contamintion is released from the harbor by dredging-related resuspension. It would also document the reduction of PCB levels in the ecosystem following dredging or other remedial actions.

Dynamics of System

We have provided advice on studies and models of the dynamics of the system that are needed to better define the extent of the problem and to select workable solutions. These recommendations are among those adopted by the Governor's Commission on the problem (ARE PCB Commission, 1982):

1) a precise delineation of PCB sediment concentrations in the New Bedford area profiled with depth;

2) an elucidation of the physical transport of PCBs in the harbor and out to Buzzards Bay, and;

3) data on bio-accumulation of PCBs by shellfish and finfish from both sediments and the water column.

Training, Education and Access to Relevant Literature

Several visitors in our laboratory from local universities have learned PCB measurement techniques and we have had extensive discussions regarding PCB analytical methodology with state agency laboratories. Our laboratory has assisted in the field sampling programs by providing equipment and expertise not initially available to the state laboratories or their contractors. A very important contribution, in our view, has been our access to world scientific literature on PCBs via the library in Woods Hole and via personal contacts with colleagues who provided us with unpublished data. By all of these methods, we have attempted to transfer the latest data and interpretation to agencies that require the information.

SCIENCE-POLICY INTERACTIONS

We learned very quickly that it was not realistic or effective to interact with only one level of government. Figure 5 provides a diagram of the main agencies and groups with which we have had contact up to this time. This figure shows only the major participants in one specific environmental issue, yet it readily depicts the complexity of the system involved in the decision-making concerning clean-up of the harbor. Each of the agencies requires scientific information at some time and at varying degrees of sophistication. The scientist who supplies this information needs to understand something of the system's complexity if his input is to be effective. Our interactions at the local, state and national levels of government were with both elected and appointed officials. No mechanism exists to guarantee communication between government entities; thus, we found that information we provided to one level of government was often not passed through to other levels in the initial stages of our interaction.

Our most serious problems in working with agencies on this PCB contamination issue were: (i) establishing our motives and credibility, and (ii) understanding the problems and constraints of the government officials and agencies. Workshop meetings of interested parties for the simultaneous communication to all concerned can be an effective approach to information transfer. Also, letters with copies to all concerned may prove effective to communicate quickly to a smaller audience.

An important issue now facing us is to know how and when to disengage from the present level of active participation once our most significant contributions have been made. If the scientific data have been transferred successfully, research scientists should, at some point, reduce their active participation in an issue and allow government agencies and their contractors to implement solutions to the problem in question. Decisions by government agencies must include consideration of political, social and economic factors, and the physical or biological scientist does not bring any more expertise to these aspects of the problem than any other citizen. Thus, the scientist cannot insist on veto power over all actions taken by an agency in the resolution of an environmental issue.

We have been concerned throughout this entire episode to alert the elected and appointed officials and the public to the serious nature of the problem without creating a doomsday type of atmosphere which might instigate a reaction of panic by the public that could be detrimental to the economic health of the area. We have also attempted to insure that the data being produced by multiple sources were valid and were interpreted in an environmentally relevant manner.

Flexible Financial Support - An Important Factor

We have found that our participation in the information transfer process is time consuming and requires a source of funding that is not specifically committed to the accumulation of new data. Our research and similar efforts in the United States and elsewhere in the world are largely supported by grants and contracts from government agencies. One of our research grants concerned general aspects of coastal environmental quality relating to prototype monitoring activities. We were allowed by the granting agency to apply some of this funding to the Acushnet River estuary PCB problem as a sub-project. A second grant, specifically written for our research related to this PCB problem, was initially approved for a three-year period but, in spite of excellent evaluations by the granting agency, was cancelled after one year. Fortunately, we were able to apply a small amount of unrestricted private foundation funding to continue critical aspects of this research.

The availability of such unrestricted research funds is a valuable resource which academic researchers can often use effectively in studies of critical environmental problems. This flexibility increases the ability of academic researchers to make objective assessments of a problem and to provide scientific evidence on an equal basis with legal, economic, and socio-political considerations.

SUMMARY AND RECOMMENDATIONS

We have presented one example of how academic research can play an important role in environmental quality issues. From our experience we have concluded that the transfer of scientific information from the scientists to agencies responsible for environmental management is neither automatic nor simple.

We feel that regular and frequent communication between academic scientists and elected and appointed officials is necessary and that institutional mechanisms usually do not exist to guarantee this communication. We recommend that seminars be held on a regular basis to provide an exchange of information between the generators and the users of scientific information. This ad hoc mechanism could provide a means to keep each other up to date on new plans or new findings and to define mutual concerns before an issue develops to a crisis situation. Such an activity is also a means of providing for mutual understanding of respective goals.

ACKNOWLEDGEMENTS

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FIGURES

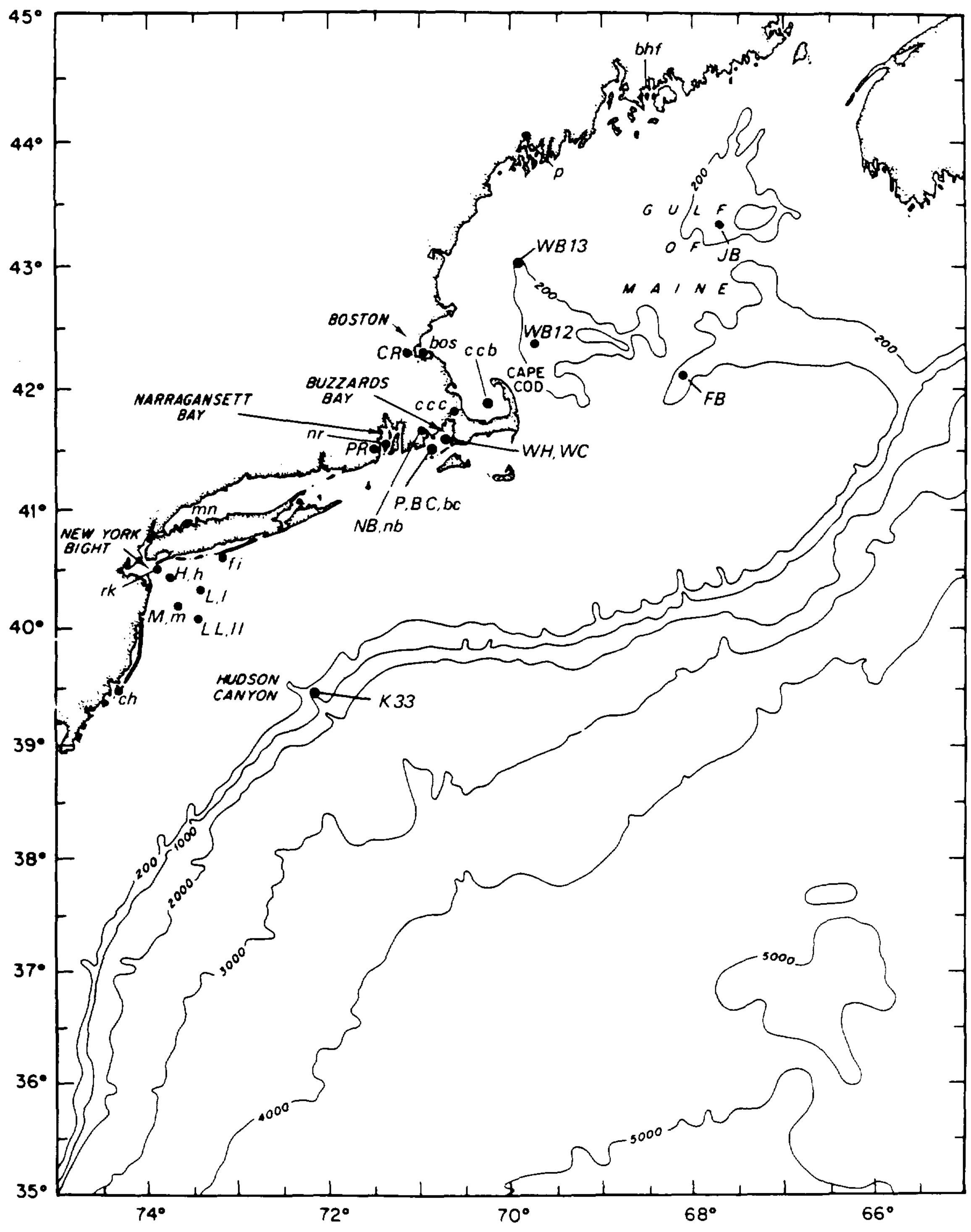
Figure 1. Northeast United States coast showing the New York Bight and the Gulf of Maine. Station locations show sampling sites for sediment and mussel samples.

Figure 2. Buzzards Bay, Massachusetts closure areas due to PCB pollution:
Area I - closed to all finfishing, shellfishing, lobstering.
Area II - closed to bottom feeding finfishing, lobstering.
Area III - closed to lobstering.

Figure 3. Massachusetts Coast U.S. E.P.A. Mussel Watch Stations.

Figure 4. High resolution glass capillary gas chromatograms (electron capture) of PCBs in Aroclor mixtures and selected samples. Numbers refer to peaks with same retention time in each chromatogram.

Figure 5. Schematic representation of interactions between suppliers of scientific information and local, state and federal agencies in the environmental problem in New Bedford. Solid lines show routes of information flow, dotted lines show major agency interactions.



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WH, WC
P, BC, bc
NB, nb
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NEW YORK
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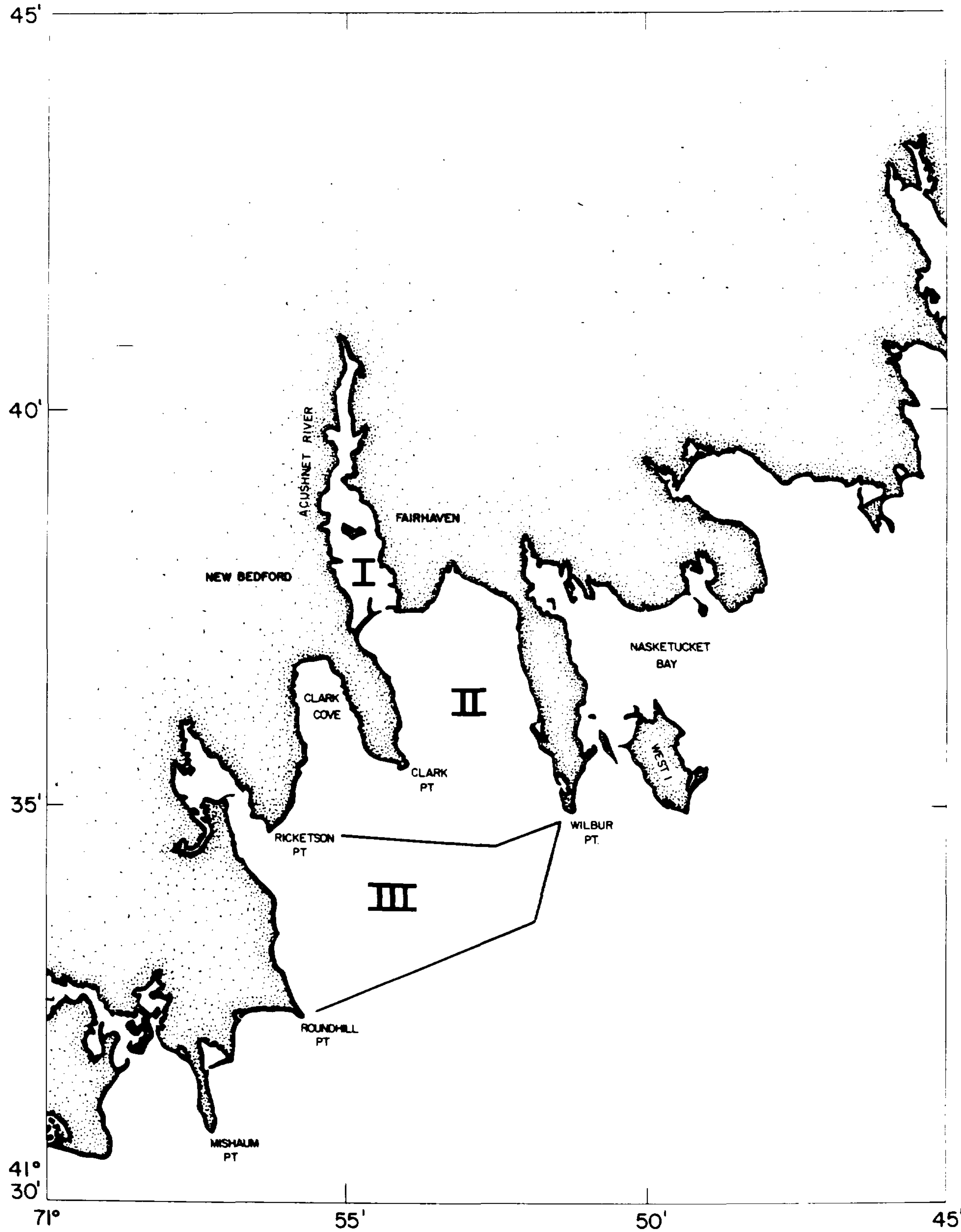
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FAIRHAVEN
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I
II
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NASKETUCKET BAY
CLARK COVE
CLARK PT
WEST I
RICKETSON PT
WILBUR PT
ROUNDHILL PT
MISHAUM PT


CAPE ANN
BOSTON
PLYMOUTH
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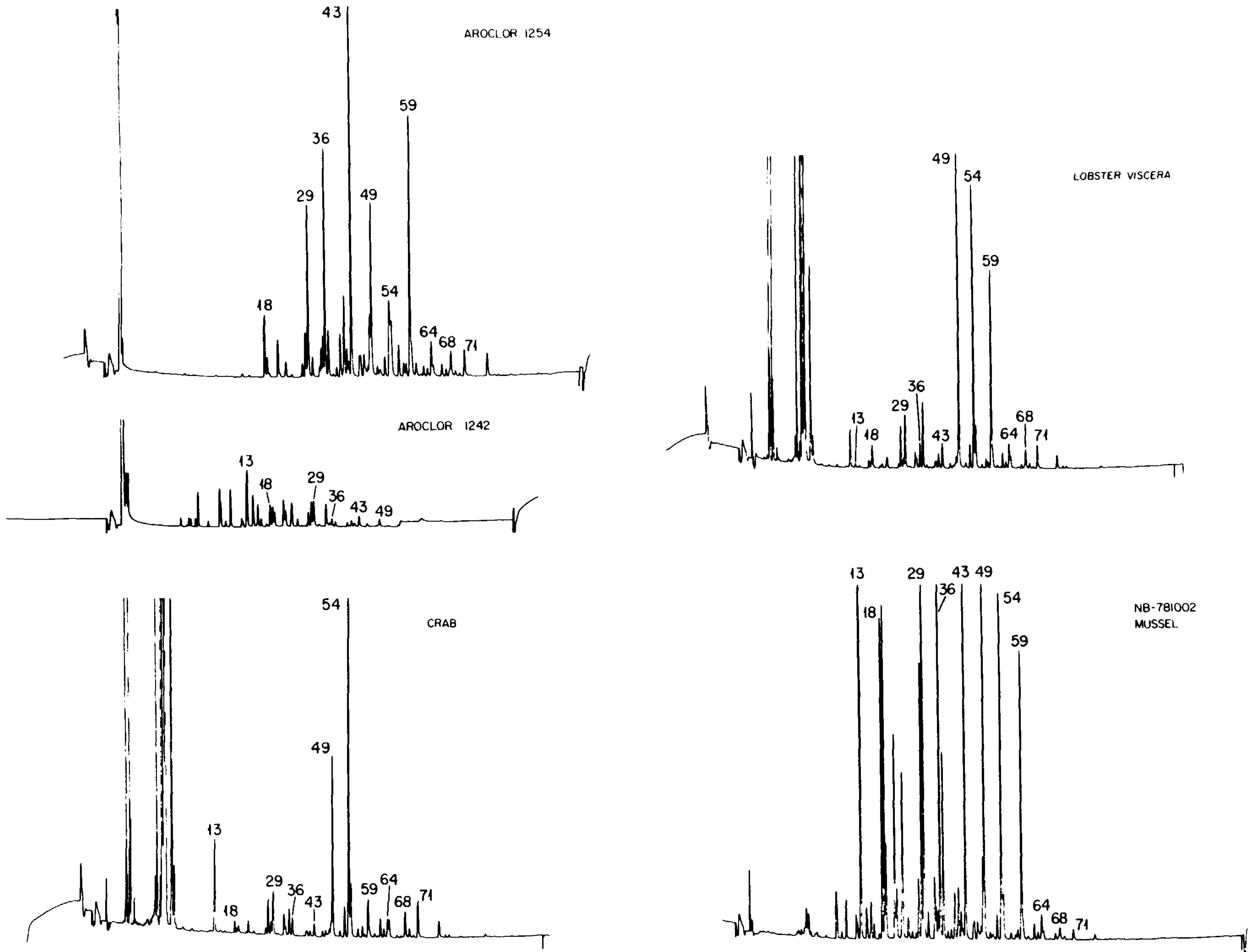
CUTTYHUNK
HARBOR
WEST POND
GAY HEAD
NANTUCKET
ESTHER IS
JETTY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AROCLOR 1242
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CRAB
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LOBSTER VISCERA
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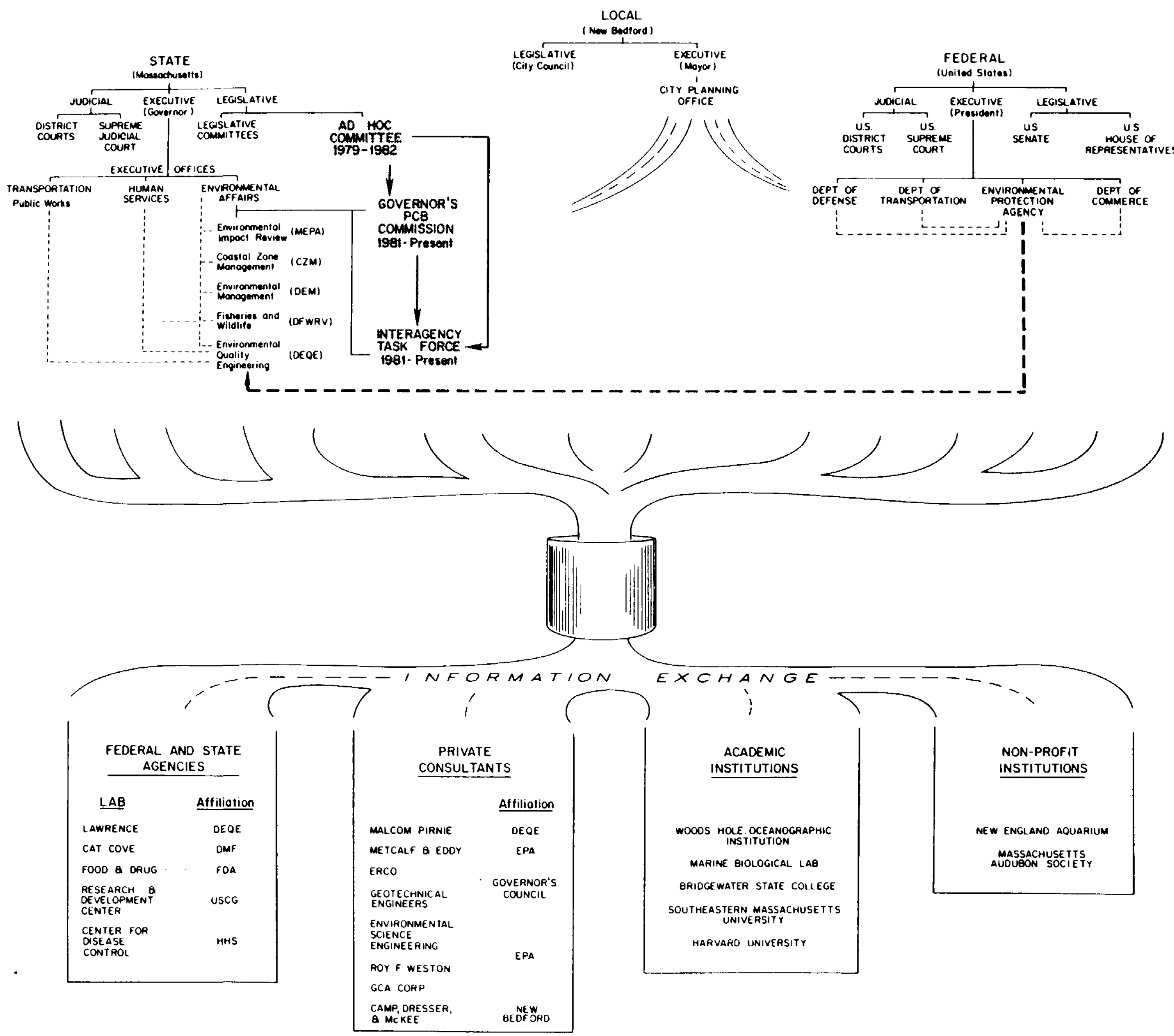

LOCAL
(New Bedford)
LEGISLATIVE
(City Council)
EXECUTIVE
(Mayor)
CITY PLANNING
OFFICE
STATE
(Massachusetts)
JUDICIAL
EXECUTIVE
(Governor)
LEGISLATIVE
DISTRICT
COURTS
SUPREME
JUDICIAL
COURT
LEGISLATIVE
COMMITTEES
AD HOC
COMMITTEE
1979 - 1982
EXECUTIVE OFFICES
TRANSPORTATION
Public Works
HUMAN
SERVICES
ENVIRONMENTAL
AFFAIRS
Environmental
Impact Review (MEPA)
Coastal Zone
Management (CZM)
Environmental
Management (DEM)
Fisheries and
Wildlife (DFWRV)
Environmental
Quality
Engineering (DEQE)
GOVERNOR'S
PCB
COMMISSION
1981 - Present
INTERAGENCY
TASK FORCE
1981 - Present
FEDERAL
(United States)
JUDICIAL
EXECUTIVE
(President)
LEGISLATIVE
U.S.
DISTRICT
COURTS
U.S.
SUPREME
COURT
U.S.
SENATE
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HOUSE OF
REPRESENTATIVES
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DEFENSE
DEPT OF
TRANSPORTATION
ENVIRONMENTAL
PROTECTION
AGENCY
DEPT OF
COMMERCE
INFORMATION EXCHANGE
FEDERAL AND STATE
AGENCIES
LAB
Affiliation
LAWRENCE
DEQE
CAT COVE
DMF
FOOD & DRUG
FDA
RESEARCH &
DEVELOPMENT
CENTER
USCG
CENTER FOR
DISEASE
CONTROL
HHS
PRIVATE
CONSULTANTS
Affiliation
MALCOM PIRNIE
DEQE
METCALF & EDDY
EPA
ERCO
GOVERNOR'S
COUNCIL
GEOTECHNICAL
ENGINEERS
ENVIRONMENTAL
SCIENCE
ENGINEERING
EPA
ROY F WESTON
GCA CORP
CAMP, DRESSER,
& McKEE
NEW
BEDFORD
ACADEMIC
INSTITUTIONS
WOODS HOLE OCEANOGRAPHIC
INSTITUTION
MARINE BIOLOGICAL LAB
BRIDGEWATER STATE COLLEGE
SOUTHEASTERN MASSACHUSETTS
UNIVERSITY
HARVARD UNIVERSITY
NON-PROFIT
INSTITUTIONS
NEW ENGLAND AQUARIUM
MASSACHUSETTS
AUDUBON SOCIETY

TABLES

Table 1

1941	Cornell Dubilier Electronics begins production of electronic capacitors containing PCBs.
1947	Aerovox Corporation uses PCBs in electronic capacitors.
1950-70	Capacitor manufacturing continues, with unknown amounts of PCB waste discharged directly to the estuary and to the municipal sewage system.
1971	Aroclor 1016 substituted for Aroclor 1242.
1974-75	Scientists from Massachusetts Audubon Society, New England Aquarium, and Woods Hole Oceanographic Institution report presence of PCB contamination in birds and sediments of New Bedford Harbor and Buzzards Bay.
1976	U. S. E.P.A. samples wastewater effluents of Cornell Dubilier, Aerovox Corporation and New Bedford sewage treatment plants. Significant levels of PCBs reported. High levels of PCBs are also reported in sediments and marine life.
1976	Massachusetts Audubon Society and Woods Hole Oceanographic Institution scientists express concern over perceived lack of official action by state and federal agencies. The Governor and Secretary for Environmental Affairs instruct state agencies to investigate severity of problem.
1976	Initiation of intensive sampling and analyses of several different species of marine life and harbor sediments by academic scientists, state and federal agency laboratories and their consulting companies.

Table 1 (continued)

1977	Monsanto Company, the only U. S. producer of PCBs, voluntarily ceases production due to accumulating evidence of environmental and health effects.
1977	Massachusetts Department of Public Health issues warning against consumption of lobsters and bottom feeding finfish from the Acushnet River Estuary and New Bedford Harbor because concentrations of 5 ppm (wet weight) or greater PCBs are detected in edible tissue.
1977	Aerovox Corporation and Cornell Dubilier Corporation cease production of capacitors containing PCBs.
1979	Massachusetts Department of Public Health closes certain areas of New Bedford Harbor and Buzzards Bay to taking of lobsters, finfish and shellfish because of PCB contamination.
1979	An Ad Hoc Committee is formed to assess PCB contamination problem, including academic scientists, state and local agencies and private citizens.
1980	Massachusetts Department of Environmental Quality Engineering designates New Bedford Harbor PCB problem as priority issue in 1980 state EPA agreement.
1981	Secretary for Environmental Affairs establishes an interagency PCB task force. Mass. Department of Environmental Quality Engineering chairs committee and holds monthly meetings to coordinate all state activities in the area.
1981	Small scale epidemiology study of New Bedford residents reveal very high PCB concentrations in blood levels compared to other U.S. regions. Based on this and further evidence of high environmental levels, enforcement of Department of Public Health ban is fully enacted.

Table 1 (continued)

1982	Coastal Zone Management, D.E.Q.E., and U.S. Coast Guard identify "hot spot" of sediment in the Acushnet River Estuary, with several hundred parts per million to several parts per thousand PCB concentrations.
1982	Acushnet River Estuary and Harbor designated as a U.S. Superfund hazardous waste site and remedial action planning begins.

Table 2

PCB Concentrations in U.S. East Coast Mussel Watch

	10^{-9} g/g dry weight*	
	1976	1977
Maine		
Blue Hill	15	34
Sears Is.	79	105
Cape Newagan	55	85
Massachusetts		
Cape Ann	96	112
Boston	635	735
Plymouth	226	366
Cape Cod Canal	215	188
New Bedford (1978)	31,000	
Rhode Island - Connecticut		
Block Is.	102	119
New Haven	129	299
New York		
Manhasset	838	700
Fire Is.	243	133
Rockaway	575	476
Georgia (oysters)		
Sapelo Is.	17	21

*10^{-9} g/gdw = part per billion; 1000 part per billion = 1 part per million

Table 3

PCB Concentrations in Buzzards Bay Area Mussels

	10^{-9} g/g dry weight*		
New Bedford Harbor	1242	1254	Total
781002	16,000	15,000	31,000
800327	39,000	10,000	49,000
810504	11,000	12,000	22,000
East End Beach			
810504	440	920	1,400
Cuttyhunk			
800826	100	300	300
Gay Head			
790926	100	140	140
Transplants Outer Harbor			
Deploy	100	100	200
Day 17	1,000	1,300	2,300
Day 28	1,400	1,600	3,000
Day 57	1,800	2,800	4,600

*10^{-9} g/gdw = part per billion; 1000 part per billion = 1 part per million

Table 4

PCB Concentrations in Water and Particulate Matter

	10^{-9} g/liter*		
	1242	1254	Total
Water			
Outer Harbor			
Surface Water	3.9	2.8	6.7
Deep Water	61	32	93
Inner Harbor			
Surface Water	5.2	4.9	10.1
Deep Water	55	21	76
Particulates			
Outer Harbor			
Surface Water	1.6	2.8	4.4
Deep Water	1.6	2.6	4.2
Inner Harbor			
Surface Water	68	71	139
Deep Water	80	53	133

*10^{-9} g/liter = part per trillion; 1,000,000 part per trillion = 1 part per million

Table 5

PCB Concentrations in Harbor and Bay Sediments

	1242	1254	Total
	10^{-6} g/g dry weight*		
Surface Sediment			
Aerovox	730	520	1250
Pope Island	96	66	162
Inner Harbor	34	12	46
Butler Flats	11	4	15
Outer Harbor	0.2	0.3	0.5
Buzzards Bay	.1	0.1	0.1
Sediment Core, Pope Is.			
0-2 cm	96	66	162
4-6 cm	138	96	234
14-16 cm	67	36	103
20-22 cm	26	12	38
28-30 cm	.1	.1	.1
	10^{-9} g/liter*		
Pore Water			
0-1 cm	780	790	1570
3-6 cm	160	160	320
6-9 cm	130	140	270

*10^{-6} g/gdw = part per million

10^{-9} g/liter = part per trillion; 1,000,000 part per trillion = 1 part per million

Table 6

PCB Concentrations in Commercial Organisms

	10^{-6} g/g dry weight*		
	1242	1254	Total
Lobster (Viscera)			
New Bedford	.1	21	21
Buzzards Bay	.1	4	4
Nantucket	.1	0.3	0.3
Lobster (Flesh)			
New Bedford	.1	0.54	0.54
Buzzards Bay	.1	0.03	0.03
Nantucket	.1	.1	.1
Flounder			
New Bedford	0.1	26	26
Westport	0.1	0.3	0.4
Quahog			
New Bedford	1.6	1.5	3.1
Outer Harbor	0.2	0.2	0.4

*10^{-6} g/gdw = part per million